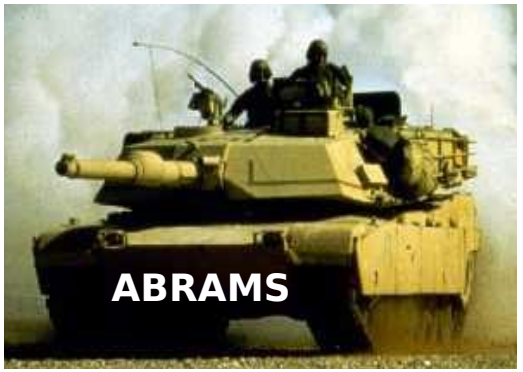
# Erosion Mitigation Technology for Large Caliber Launch Systems



**presented by**
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# LARGE CALIBER GUN EROSION

## *Direct Fire*

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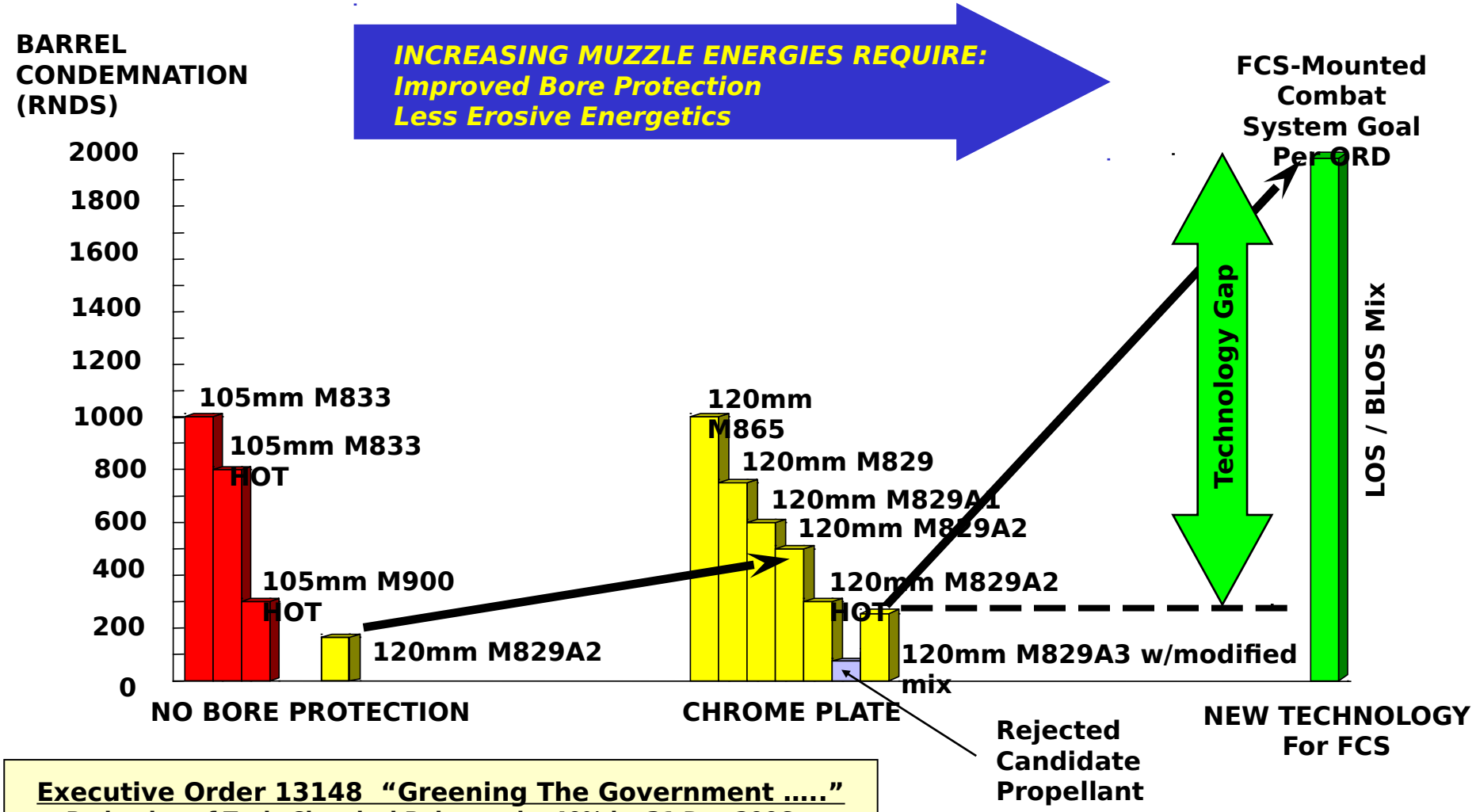


**Executive Order 13148 "Greening The Government ....."**

Reduction of Toxic Chemical Releases by 40% by 31 Dec 2006

Reduction of Toxic Chemical Usage by 50% by 31 Dec 2006

# 120mm GUN BARREL DEGRADATION

## *Classic Erosion Defined*

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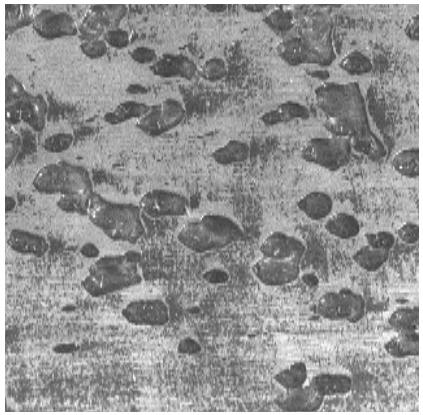
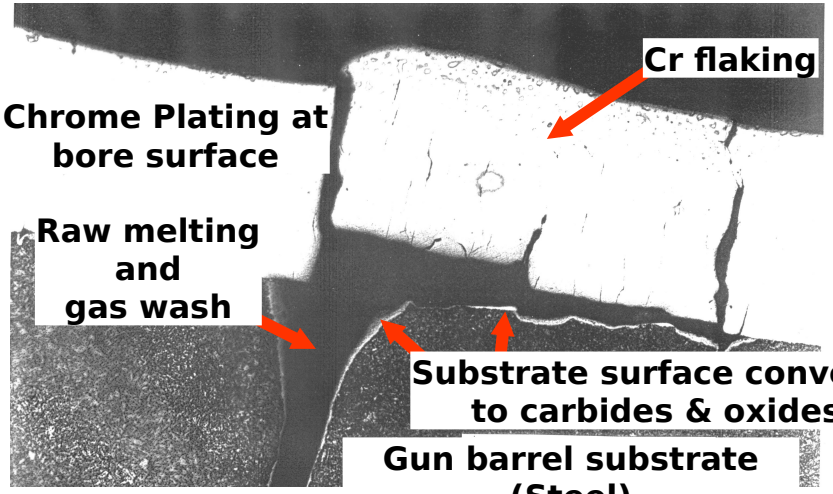
101 rounds M829
771 rounds Total



39 M829E3 Rejected candidate
214 Total rounds

**ABRAMS 120mm GUN**


Cr flaking
Chrome Plating at bore surface
Raw melting and gas wash
Substrate surface converts to carbides & oxides
Gun barrel substrate (Steel)

- HC Chrome is produced in an “as cracked” condition offering path to substrate
- HC Cr contaminants off-gas causing further material volume shrinkage and stress-relief cracking
- Combustion products:
  - Penetrate cracks
  - Alter steel substrate phase
  - Convert substrate surface to carbides & oxides
  - Lowers MP of substrate surface
- Gas wash:
  - Removes lower MP substrate surface
  - Erodes Cr foundation (compromised adherence)

Departing Cr exposes more substrate to gh velocity gas wash and further erosion

# LARGE CALIBER GUN COATING REQUIREMENTS

## *Material & Deposition Process Requirements*

U.S. Army Benet Laboratories

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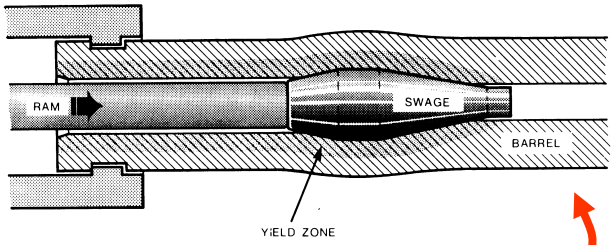
| MATERIAL CHARACTERISTIC | CRITERIA |
|---|---|
| **Melting Point** | *Cr (1875 C) or better* |
| **Elastic Modulus** | *Compatible with substrate* ***(facilitates low surface crack densities)*** |
| **YS at Elevated Temps** | *High* |
| **Fracture Toughness** | *High* |
| **Hot Hardness** | *High (appropriate)* |
| **Chemical Resistance** | *High* |
| **Coefficient of Thermal Exp.** | *Compatible with substr* |
| **Thermal Conductivity** | *Low* |
| **Reaction w/ Rotating Band** | *Inert* |
| **Phase Transformations** | *None* |




| PROCESS CHARACTERISTIC | CRITERIA |
|---|---|
| **Deposition Temperature** | *Less than 357C* ***(post autofrettage thermal soak limit)*** |
| **Deposit Rate** | *1 mil of coating material per hour* |
| **Surface Finish** | *Equal or better than 32 RMS at deposition* |
| **Deposition Length** | *58 Calibers or greater* |
| **Hazardous Impacts** | *None or limited* |

# EROSION RESISTANT COATING MATERIAL SELECTION

## *for Large Caliber Guns*

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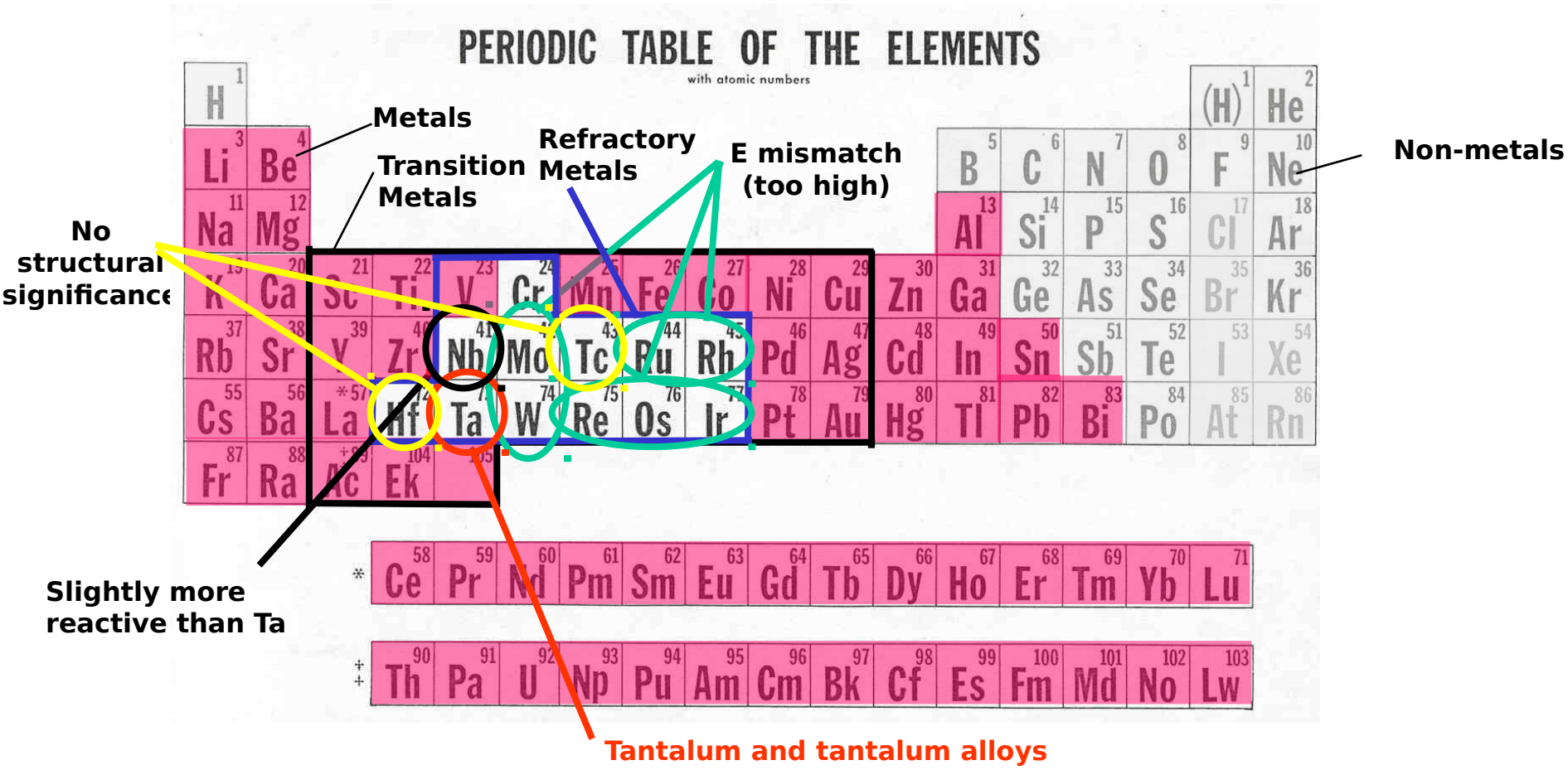


Rh, Ru, Tc, Hf, Nb, Mo, Ta, W, Re, Os, & Ir exceed MP of

# COATING DEPOSITION PROCESS SELECTION

## *for Large Caliber Guns*

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| FUNCTIONAL REQUIREMENTS | PROCESS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Molten Salt | Plasma Spray | Chem. Vapor Dep. | Ion Implant. | Ion Plate | Explosive Bonding | | Metal liding | Aqueous Electro-Dep | Cyl Magnetron Sputtering |
| Autofrettage Stresses Protected | | | | ✓ | ✓ | | | ✓ | ✓ | |
| No Post-process Surface Finish Req | ✓ | | | ✓ | | ✓ | ✓ | ✓ | ✓ | |
| Acceptable Deposition Rate | ✓ | ✓ | ✓ | | | ✓ | | ✓ | ✓ | |
| Proper Process Aspect Ratio | | | ✓ | | | | | ✓ | ✓ | |
| Accept Dim. and Densities over 50 cal | | | | | | | | ✓ | ✓ | |
| Acceptable Adhesion | ✓ | | | | | ✓ | | ✓ | ✓ | |
| Dry Process | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | |
| Eliminate Hazardous Materials | | | | ✓ | ✓ | ✓ | | | ✓ | |
| Eliminate Air / Water Contamination | | | | ✓ | ✓ | ✓ | | | ✓ | |

# 120mm GUN BARREL MANUFACTURING PROCESS

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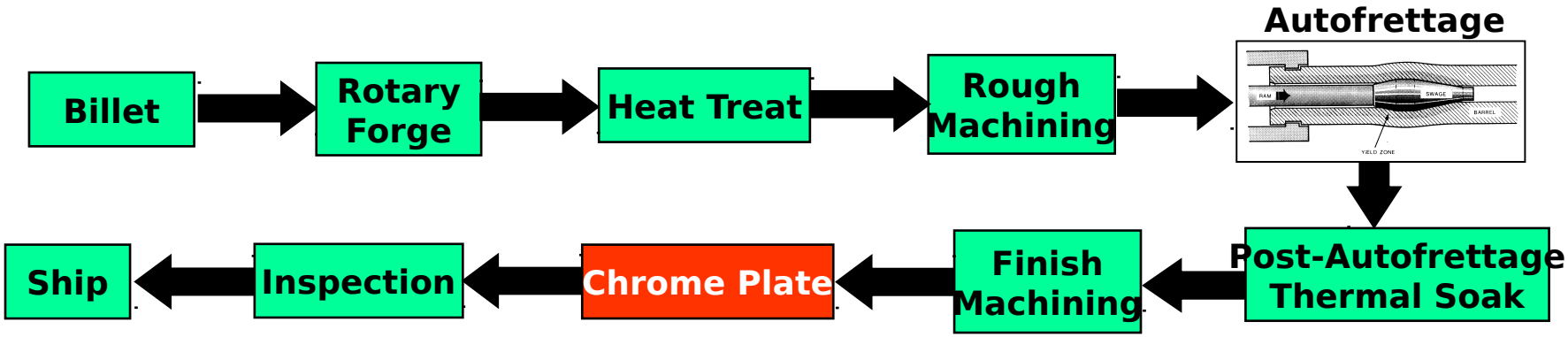

Rotary Forging

Machining

Chrome Plating

Fielding

# TECHNICAL APPROACH

## *Cylindrical Magnetron Sputtering*

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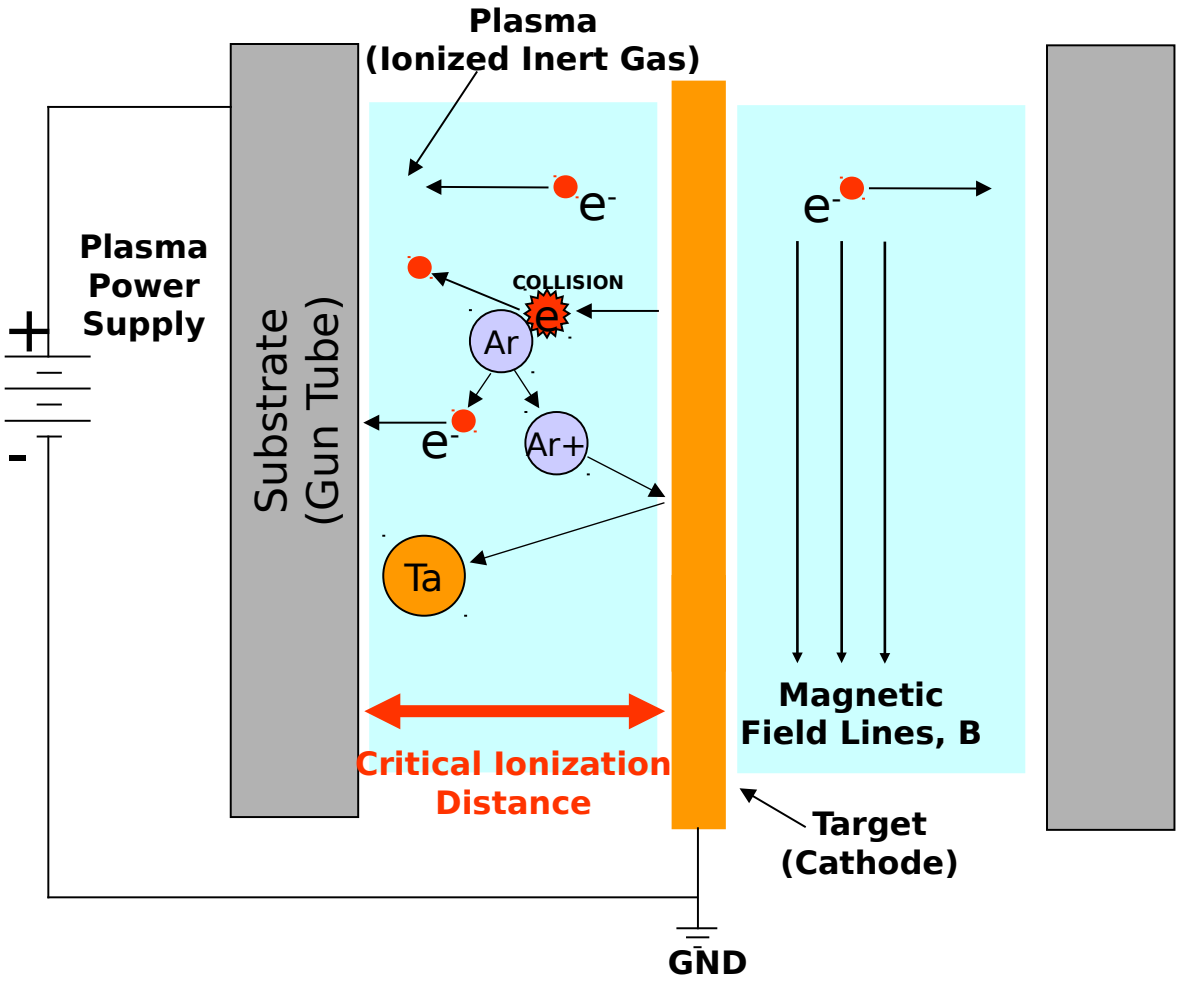


## ***ADVANTAGES***

- Environmentally benign
- Can deposit high melting point materi
- Acceptable deposition rates
- Autofrettage stresses protected
- No post-process surface finish req
- Accept dim. and densities over 50 cal
- Dry process
- Eliminate hazardous materials
- Eliminate air / water contamination
- Best suited for large caliber guns
  I.e. Larger target-to-tube distances

# LARGE CALIBER EROSION MITIGATION TECHNOLOGY

## *Accomplishments and Plans*

U.S. Army Benet Laboratories

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| ***Task*** | ***Accomplishment*** |
|---|---|
| Demonst[illegible] resistant behavior via *Electrodeposition by Fused Salts* | [illegible]arrels (liners)<br>• 110 rounds from 105mm M68 barrel (liners) |
| Demonstrated *Biased Triode Sputtering* Process Technology | • 1500 rounds at 150 rounds/min for 10 bursts from 20mm M61A1 barrels (liners) |
| Demonstrated *Cylindrical Magnetron Sputtering (CMS)* for hi L/D Barrels | • Coated full length “Abrams-Simulator” 45mm barrels<br>Origin wear rate equivalency demonstrated |
| Demonstrated enhanced adhesion with *CMS Ion Bombardment Sputtering via Pulsed Technology* | • 120mm barrel sections. Results show decreased<br>[illegible]ck density indicating increased barrel life |
| Building *Pre-Production Sputtering Platform* at Watervliet Arsenal | • Full-length CMS platform currently under construction at Watervliet Arsenal.<br>Initial Operational Capability by June 04. |
| Coat inserts & full length smoothbore, Large Caliber Barrels - *Abrams, FCS-LOS* | |
| Fire coated full length smoothbore, Large Caliber Barrels - *Abrams, FCS-LOS* | FY ’04 – ‘05 |

*Summary of*

# TECHNICAL METRICS

## *Advanced Coatings for Large Caliber Guns*

U.S. Army Benet Laboratories — ARDEC

| CURRENT CHARACTERISTIC | Current state of HC CHROME PLATING | Desired end state for SPUTTERING | VERIFICATION TECHNIQUE | STATUS |
|---|---|---|---|---|
| Coating Morphology | Zone 2 | Zone 2 | Microscopy | yes |
| Coating Phase | Single | 100% Alpha (Ta) | Microscopy | yes |
| | | bcc (Cr) | Microscopy | yes |
| Hardness | 1100 Knoop | 200 - 300 Knoop | Microhardness (Ta) | yes |
| | | | Microhardness (Cr) | yes |
| Thermal Shock Resistance | Poor | Excellent | Pulsed Laser | yes |
| | | | Vented Erosion Sim | yes |
| Adhesion / Cohesion | Excellent | Excellent | Groove Testing | yes |
| | | | VES (Ta) | yes |
| | | | VES (Cr) | yes |
| Distribution over Length | .002 - .006 in. | Less than .0005 | | |
| Microscopy | yes (80”) | | | |
| Distribution around ID | .002 - .006 in. | Less than .0005 | | |
| Microscopy | yes | | | |
| Deposition Rate | .001 inches/hr | .001 inches/hr | Microscopy | no (.00075) |
| Coating Thickness | .002 - .006 in. | .004 - .006 in. | Microscopy | yes |

# INTERIM VALIDATION

## *In-process Assessment Challenge*



**Large Caliber Testing** 400 rounds x $3500 ea = $1.4M plus range/personnel costs

- Too costly as an in-process assessment tool
- Design of Experiments nightmare
- Best used as final assessment against program metrics

**Sub-Scale Development & Testing**

- Economical approach ***as long as deposition process is scaleable***
- PVD processes for ID surfaces have proven to be “size-sensitive”
- Target-to-substrate distance is critical for consistent plasma generation
  - *Coating deposition rate*
  - *Coating distribution over length and circumference*
  - *Coating morphology, phase and adhesion quality*
- 25mm / 45mm experiences did not matched large caliber process needs/achievements
- Achieved improved adhesion on 1st 120mm deposition

**Best approach** - **Full scale process development w/valid sub-scale test methodology**

- requires a test methodology that minimizes deviations from gun parameters
- no multiple process development cycles
- no scaling assumptions

# INTERIM COATINGS VALIDATION

U.S. Army Benet Laboratories

## *Vented Erosion Simulator (VES) Testing*

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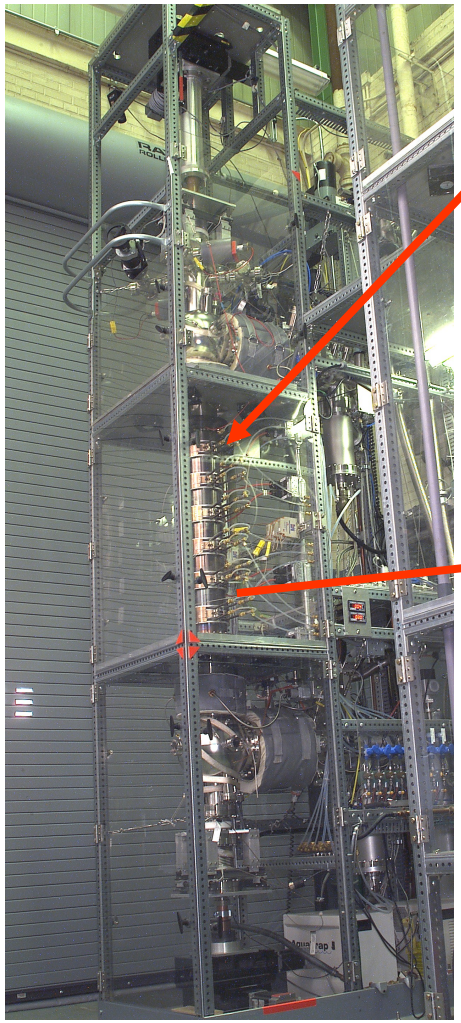

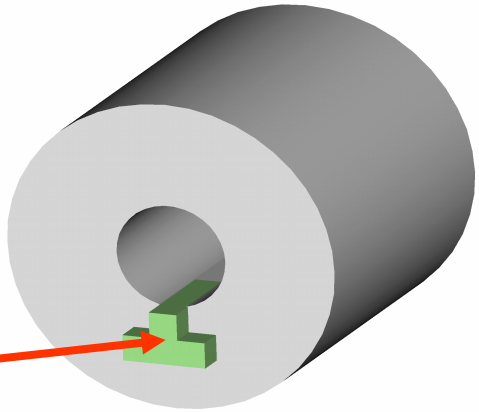


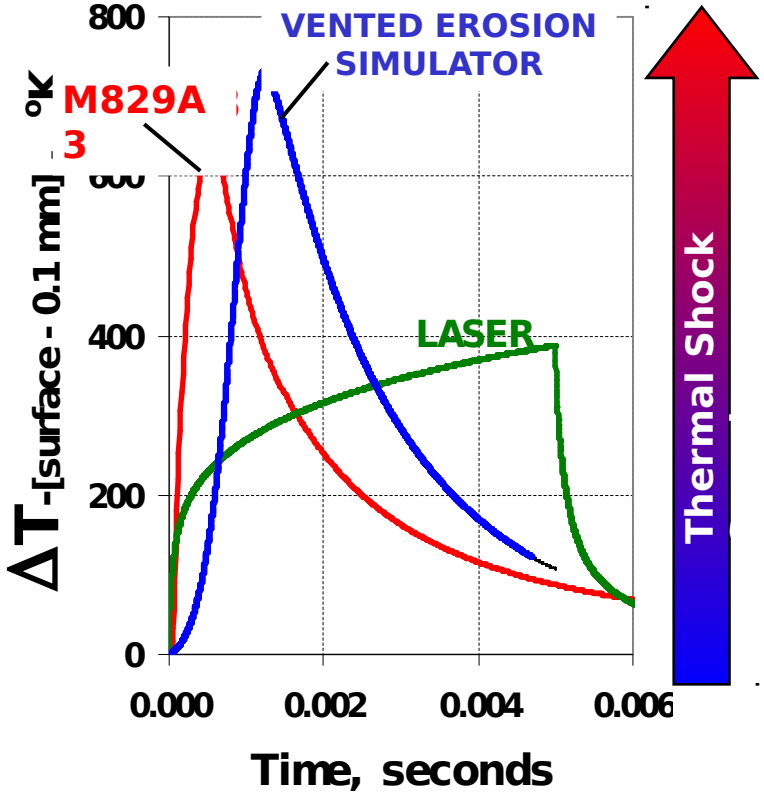


- Flame T & chemistry similar to M829A2/M829A3
- Accepts Large Caliber coated coupons *(eliminates process scaling)*
- Ballistically modeled & validated
- Substrate transformed to same depth as Lg Cal Gun
- Maintains critical T observed in current gun barrel

# INTERIM COATINGS VALIDATION

U.S. Army Benet Laboratories

## *Vented Erosion Simulator (VES) Testing*

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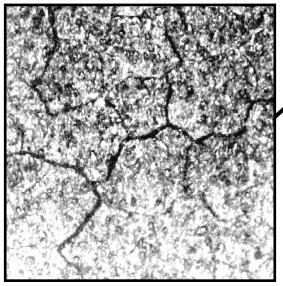
**SURFACE CRACK DENSITY**

**CROSS-SECTION**

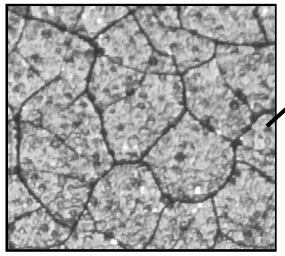
**HC-Cr**

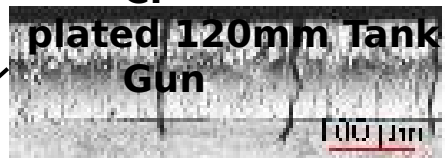


**118 M829A3 Rounds fired from a production HC-Cr plated 120mm Tank Gun**

**Thermal-Chemical Erosion Equivalency of Vented Erosion Simulator**

**HC-Cr (VES)**

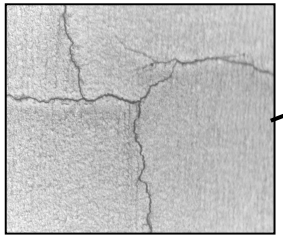





**100 VES shots on a production HC-Cr plated 120mm Tank Gun Section**

**Erosion Reduction with CMS Tantalum as compared to Electrodeposited HC-Chromium**

**CMS-Cr (VES)**



**100 VES shots on a Sputtered Tantalum coated 120mm Tank Gun Section**

***LOWER CRACK DENSITY = BARREL LIFE***

***LO***

# LARGE CALIBER Pre-PRODUCTION Demonstration Platform

## *at Watervliet Arsenal – Initial Testing - June 04*

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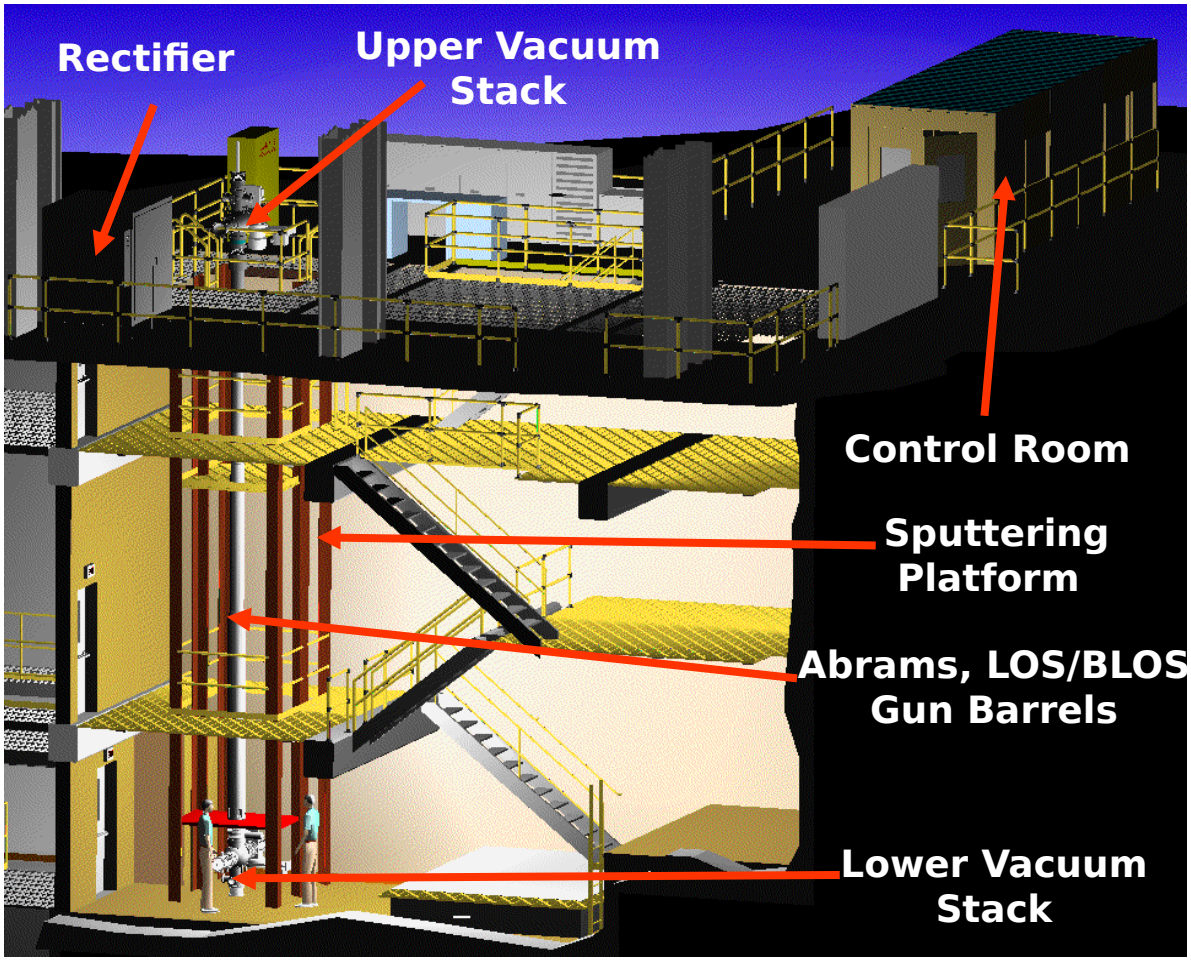

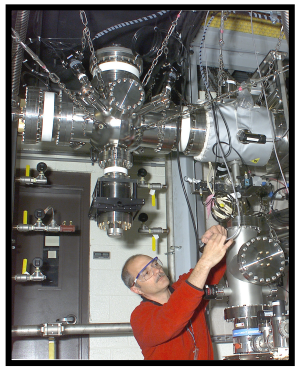

# UPCOMING FIRING DEMONSTRATIONS

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## *Advanced Sputtered Coatings*

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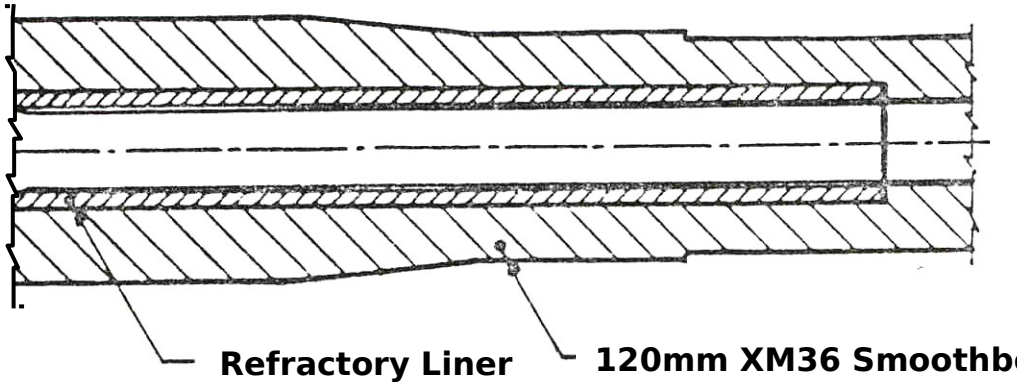


**120mm XM36 Firing Test #1**

- 120mm coated, shrink-fit liner
- May-June 04

FUTURE COMBAT SYSTEMS
FCS
One Team – The Army/DARPA/Industry

**120mm XM36 Firing Test #2**

- 120mm coated, shrink-fit liner
- Oct-Nov 04

**120mm XM36 Sub-Scale Development & Testing**

- Full-length monoblock coating test
- Mid FY05

# BARREL COATING TECHNOLOGY

## *System Application Graphic*

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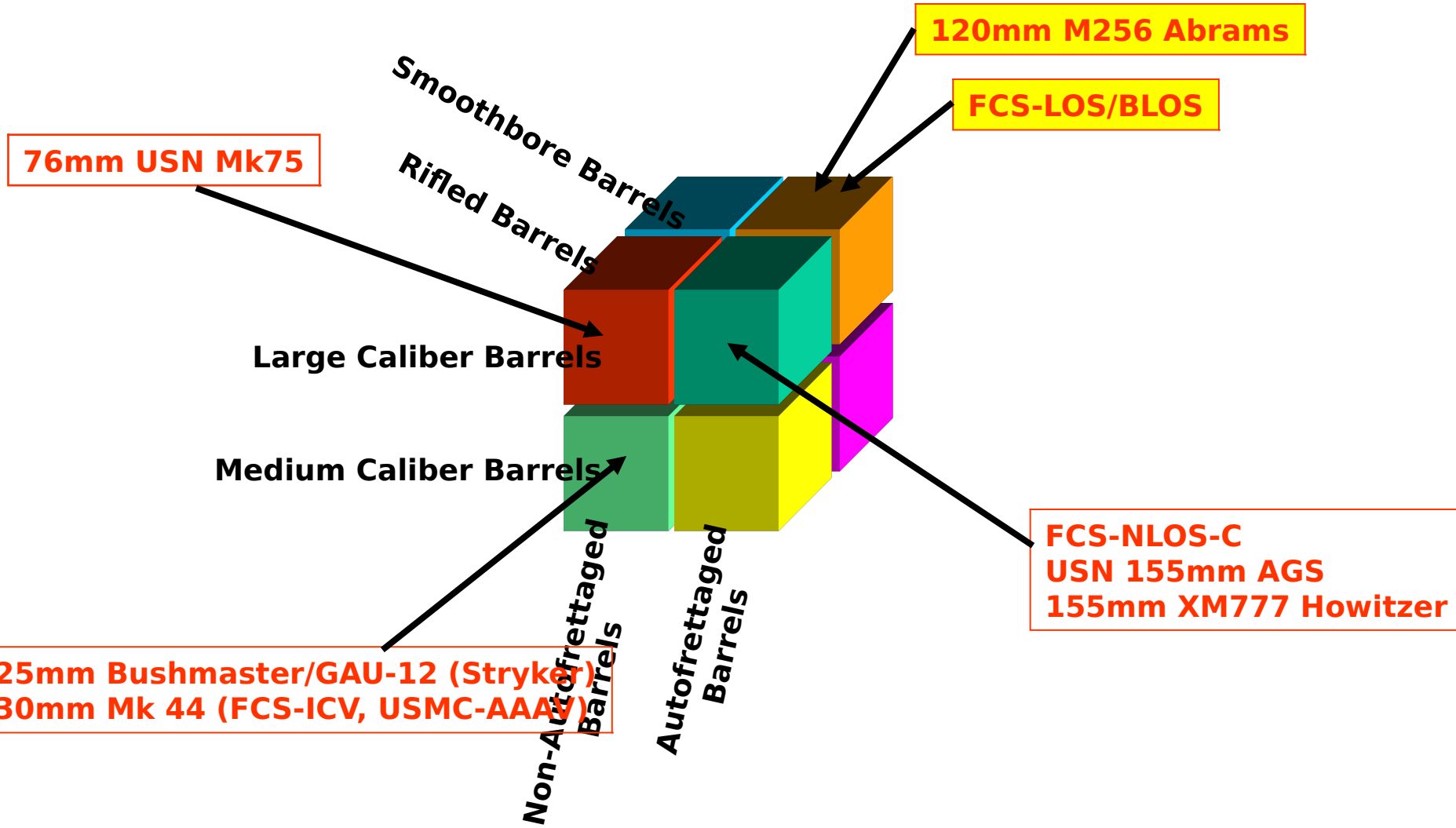

# SUMMARY

- **Cylindrical Magnetron Sputtering results encouraging for large caliber systems**
  - Increased adhesion and bulk properties
  - All laboratory metrics achieved *(still improving deposition rate)*

- **Technology moving forward but slower than desired**
  - 30% loss in program funding – *War on Terror, FCS cuts, etc.*

- **Upcoming 120mm XM36 tests should be insightful**

- **Large Caliber Full-length Pre-Production Platform Initial Testing by June 2004**

- **Will one coating technology address all platforms ???**
  - Large Cal vs. Med Cal
  - Autofrettaged vs. Non-Autofrettaged
  - Smoothbore vs. Rifled bore